AMANDA

ANTARCTIC MUON AND NEUTRINO DETECTOR ARRAY

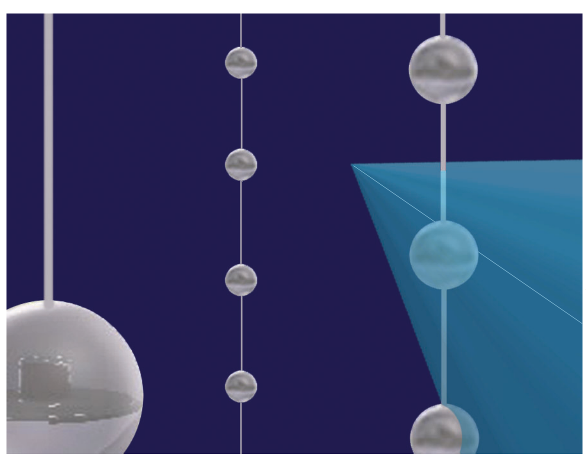
http://amanda.physics.wisc.edu

Astrophysicists have buried more than seven hundred sensors deep in the Antarctic ice cap to watch for the faint flashes of light produced by the passage of high energy subatomic particles. These sensors comprise the Antarctic Muon and Neutrino Detector Array (AMANDA), the first of a new generation of high energy neutrino telescopes. Conceived in the late 1980s and constructed over the past five years, AMANDA utilizes the clear Antarctic ice to hunt for these elusive particles. The AMANDA detector searches for energetic neutrino emissions from active galaxies as well as supernova explosions within our own galaxy. As AMANDA evolves into a cubic-kilometer detector called IceCube, it will be able to study quasar-like objects that are some of the most violent and least understood objects in the universe.

Neutrinos

Neutrinos are ghost-like particles, produced in the decay of radioactive elements and elementary particles, such as pions and muons. They are extremely antisocial, interacting only feebly with matter. Their existence was first suspected in 1931 when it was observed that energy and momentum were missing from the decay of radioactive nuclei. It was only in the 1950s that neutrinos were actually observed by Clyde Cowan and Frederick Reines, a discovery for which Frederick Reines won the 1995 Nobel Prize for Physics. Even today, neutrinos remain so mysterious that the question of whether they have mass is only now being resolved.

The feeble interaction of neutrinos with matter makes them ideal astronomical messengers. Unlike photons or charged particles, neutrinos can travel across the universe without hindrance, undeflected by interstellar magnetic fields and unabsorbed by intervening matter. But this same anti-social quality makes these cosmic neutrinos fiendishly difficult to detect. Most of the trillions of neutrinos that stream through every square meter of the Earth's surface every second leave no trace at all. But, on rare occasions, a passing neutrino crashes into a proton or neutron. From the wreckage of the atomic nucleus emerges a particle called a muon (a heavy electron), which can travel hundreds of meters or even kilometers through the surrounding ice. Unlike the invisible neutrino, the muon gives off a shock wave of blue light as it travels through the ice, much like the bow wave of a boat passing through the water. By



Emerging from a crash with a neutrino, a muon preserves the neutrino's trajectory and emits blue light that the telescope's sensors detect.

The AMANDA detector, buried 1500 meters beneath the South Pole, consists of more than 700 sensors arranged in a cylinder 1000 meters tall and 200 meters in diameter. The Eiffel tower is shown to illustrate the scale.

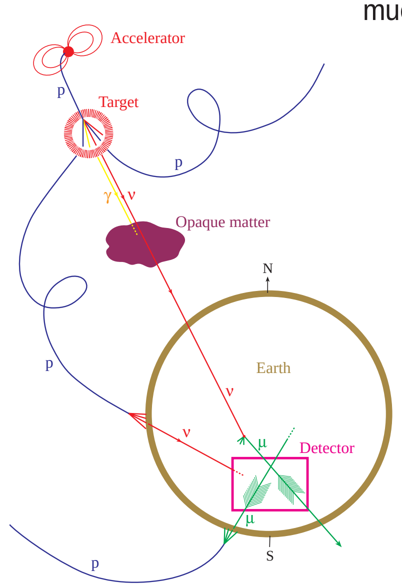
Neutrinos emitted by distant, energetic objects can travel directly to a detector on the Earth.

Optical sensors are strung like beads on electric cables and frozen 1500 meters below the surface of the ice.

The summer drilling camp at the South Pole Station.

detecting this “bow wave” of light we can reconstruct the muon’s path. Since the muon travels in the same direction as the parent neutrino, we can point back along the muon’s track to determine where in the sky the neutrino came from.

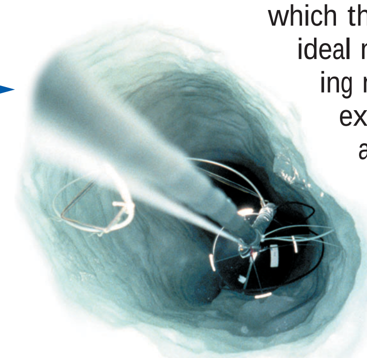
Unfortunately, muons come not only from neutrinos but also, and far more frequently, from cosmic rays striking the Earth’s atmosphere. To ensure that we are seeing muons from neutrinos,

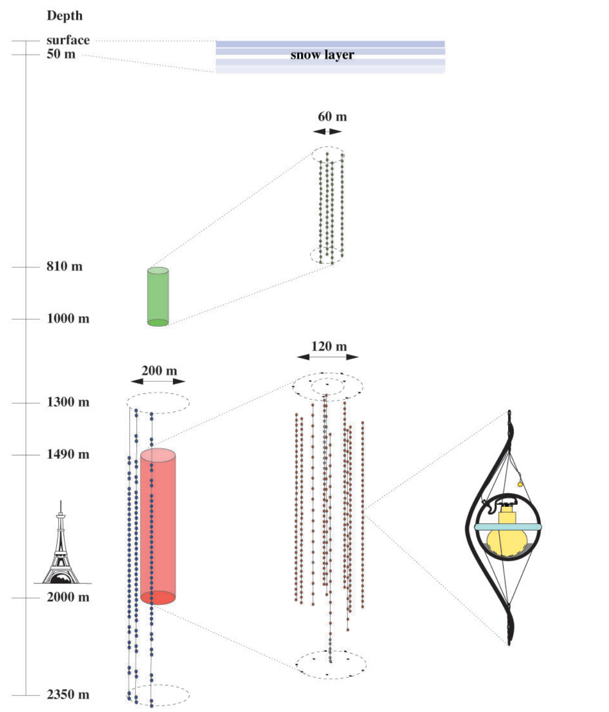


we look downward through the Earth and into the northern hemisphere, using the planet itself as a giant cosmic ray filter. Since neutrino interactions are so feeble, they can easily pass through the Earth unhindered. No other known particle can do so.

The AMANDA Project

A neutrino telescope must be huge, transparent, dark, and as far as possible below the surface to shield it from cosmic rays. To overcome this challenge, neutrino astrophysicists exploit the deep oceans or the 3000-meter-thick Antarctic ice cap. The international group (see back page) of AMANDA scientists is using this Antarctic ice, which they consider an ideal medium for detecting neutrinos: it is exceptionally clear, and almost completely free of radioactivity. Light from passing muons can travel hundreds





AMANDA as of 1998
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

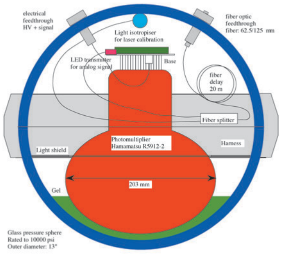
zoomed in on one
optical module (OM)

of meters through the ice, and 1500 meters below the surface, the ice is otherwise completely dark.

Surprisingly enough, despite its remoteness, Antarctica is also a much more accessible place to build a neutrino telescope than the deep ocean. Operating from the U. S. South Pole Station, detectors can be deployed from a solid ice surface rather than from a ship. Also the detectors can be connected directly to a control room on the ice surface, rather than relying on submarines operating on the ocean floor to establish the connections to shore stations miles away. These advantages certainly outweigh the relative remoteness of the site.

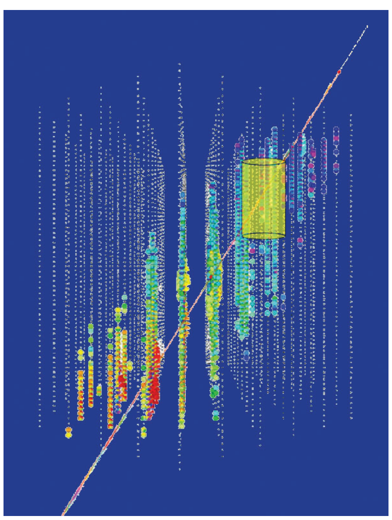
The present Antarctic Muon and Neutrino Detector Array consists of over 700 modules buried at the South Pole 1500 meters below the surface of the ice. Each module consists of a photomultiplier tube for detecting light, housed in a glass pressure vessel. The modules are arranged like 500-meter-long strings of beads on 19 electrical cables leading up to a control room at the surface. To bury a string of modules we use a jet of hot water to melt a hole approximately 50 centimeters in diameter and 1500 meters deep; the string is lowered into the water and allowed to freeze in place. The AMANDA detector was completed in the austral summer of 1999-2000.

Each module consists of a photomultiplier tube for detecting photons, housed in a glass pressure vessel.



The Ice Cube Project

Large as it is, AMANDA is still a prototype capable of seeing only the brighter (and closer) sources of neutrinos. Just as in optical astronomy, bigger telescopes let you see farther and more clearly, so in the first years of the new millennium, we plan to build a larger detector, comprising nearly 5000 modules scattered through a cubic kilometer of ice. This detector will be known, appropriately enough, as IceCube. It will be capable of detecting neutrino sources from the farthest edges of the universe.



IceCube will encompass AMANDA (yellow cylinder). Its much larger size improves both the accuracy with which we can project the origin of a detected neutrino, and our capacity to measure its energy. Here, the color coding of the sensors, following the rainbow from red to purple, labels passage of time along the particle track.

High Energy Astronomy

The AMANDA and IceCube high energy neutrino detectors are ideal tools to probe the most distant, highest-energy objects in the universe. Neutrinos are the only messengers that can bring us direct information about the most violent cosmological events. The cosmic microwave background left over from the Big Bang renders space opaque to high-energy photons, and interstellar magnetic fields deflect nearly all charged particles such an event might produce.

University of Wisconsin graduate student John Jacobsen preparing a module to be lowered into the ice.

The history of astronomy has shown that forays into new energy regimes using new viewing windows, such as neutrinos, have invariably resulted in the discovery of new phenomena. AMANDA and IceCube have the potential to discover supersymmetric particles which have been hypothesized to make up the dark matter in the universe. They could also contribute significantly to the determination of the actual masses of the neutrinos. Already, AMANDA searches continuously for supernova explosions in our Galaxy and for the birth of the supermassive black holes that power quasars. It is investigating objects discovered by space-based gamma-ray detectors such as gamma-ray bursters, and probing the high-energy emission from active galaxies. Even more exciting, AMANDA and IceCube may discover entirely unexpected phenomena.

This galaxy is designated a type 2 Seyfert, a class of mostly spiral galaxies that is a part of a larger class of objects called Active Galactic Nuclei or AGN. AGNs are a suspected source of gamma rays and neutrinos.

RESEARCH

DISCOVERY

A physics graduate student, Jodi Cooley (right), describes to high school physics students the workings of a photomultiplier tube, the optical sensor housed in each glass module.

Education and outreach

AMANDA and IceCube scientists and engineers are not only building and analyzing data from these remote and unique instruments. They also are enabling others to experience the excitement of learning and discovery that they feel. They believe that, parallel with the transformations in science that accompany the development of major new instruments, there should be improvements in the ways all students and the public learn about and participate in science. The IceCube Education Resource Center is helping these scientists develop excellent educational resources, and generate meaningful ways to communicate with people-young and old, in all walks of life, and with different levels of interest in this new frontier of particle astrophysics.

Participating Institutions

Clark Atlanta University, USA
DESY - Zeuthen, Germany
Lawrence Berkeley National Laboratory, USA
South Pole Station, Antarctica
Southern University and A & M College, USA
Stockholm Universitet, Sweden
Universität Mainz, Germany
Universität Wuppertal, Germany
Université Libre de Bruxelles, Belgium
Université de Mons-Hainaut, Belgium
University of Alabama, USA
University of California–Berkeley, USA
University of California–Irvine, USA
University of Delaware, USA
University of Kansas, USA
University of Maryland, USA
University of Pennsylvania, USA
University of Wisconsin–Madison, USA (lead)
University of Wisconsin–River Falls, USA
Uppsala Universitet, Sweden

LEARNING

Agencies supporting AMANDA/IceCube include:

- German Ministry of Research and Education
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- Knut and Alice Wallenberg Foundation, Sweden
- National Fund for Scientific Research, Belgium
- Swedish Natural Science Research Council
- Swedish Polar Research Secretariat
- University of Wisconsin Alumni Foundation
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- U.S. National Science Foundation, Office of Polar Programs
- U.S. National Science Foundation, Physics Division

EDUCATION

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